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Administration

EIA's International Electricity Market Model (IEMM) Technical Requirements

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Background

The Office of Energy Analysis (OEA) within the U.S. Department of Energy, U.S. Energy Information Administration analyzes energy supply, demand, and prices including the impact of financial markets on energy markets; prepares reports on current and future energy use; analyzes the impact of energy policies; and develops advanced techniques for conducting energy information analyses. This Office also oversees the planning and execution of EIA's analysis and forecasting programs to ensure that EIA models, analyses, and projections meet the highest standards of relevance, reliability, and timeliness. The EIA website is located at: http://www.eia.gov/.

OEA has a requirement for development of an International Electricity Market Model (IEMM). The proposed IEMM shall include the capability to project electricity capacity and generation by fuel and technology, and electricity consumption and wholesale and retail prices for each of the four end-use sectors represented in WEPS+[1], utilizing regional electricity demands and fuel supplies for each of the 16 WEPS+ regions annually consistent with EIA's International Energy Outlook (IEO) projection period (currently through 2040). The proposal project schedule consists of four stages: 1) preparation of a Component Design Report, 2) development of a prototype model, 3) implementation of the full model, and 4) post implementation support. In addition, the proposal requirements include that the approach described in each CDR shall not be limited to the use of a specific platform/model, provides the government with unrestricted technical data rights, and CDRs become government property.

A key design consideration of the IEMM is the level of aggregation: model outputs shall be aggregated to the same regional, temporal, and sectoral granularity of the WEPS+ model; IEMM itself shall have additional granularity in order to best represent global electricity markets. EIA expects the granularity that best represents international electricity markets to change over time so the model should be able to easily incorporate more detailed data as it becomes available. Therefore the internal representation of regional, temporal, and sectoral granularity within IEMM and the way it is aggregated for reporting to WEPS+ shall be made easily reconfigurable (e.g., via changes to input files rather than changes within model code). This flexibility in granularity shall apply as an additional consideration for all other requirements in this document.

Model specifications

I. Electricity demand representation (load shapes)

The model will receive as an input the annual demand by sector and shall develop a system load curve for each region to be used for capacity planning and dispatch. The load curves should incorporate transmission and distribution losses to reflect the generation requirements in each load segment. The number of segments should be sufficient to represent peak and off-peak time periods, as well as seasonal and time-of-day distinctions. The model shall represent a peak segment to determine the need for total capacity and account for the need for peaking capacity.

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[1] The modeling approach for the electricity forecast in the IEO is discussed in *World Energy Projection System Plus Model Documentation 2011: World Electricity Model (*http://www.eia.gov/forecasts/archive/m078 (2011).pdf).

A representation of day/night across the load segments is important with the growing penetration of wind and solar technologies worldwide. The total number of load segments, and the hours attributed to the segments, should be flexible and developed to best represent the markets in each region without adversely affecting model run time. The system load curve should be able to vary over time and respond to different rates of growth across the sectors (i.e., shape should become 'peakier' if residential growth increases rapidly).

II. Implement capacity planning and dispatch (determine generation, capacity, and consumption) as an economic model

a. Capacity (generator) dispatch

One major purpose of the model is to obtain defensible projections of capacity, fuel consumption, and generation levels by country and/or region of the world. The primary focus in model development should be the application modeling approaches that reasonably represent planning and operational activities. The model shall represent a dispatch of generators, based on the total capacity available, taking into account operating constraints of the different technologies, operational and system constraints, as well as potential policy requirements such as renewable generation targets or emission limits. The dispatch should respond to varying market conditions and be sensitive to variable operations and maintenance costs and fuel prices, including any carbon fees. To represent a realistic generation mix, the model must be able to represent a range of costs and characteristics (such as heat rate) within a given plant type. The model should be flexible in the level of detail modeled and be adaptable based on the data availability for different regions. For example, as more data is available, more vintages of existing capacity could be represented in the dispatch with unique costs and characteristics. The model should have the flexibility to allow different levels of capacity disaggregation by plant type and region.

The model shall be able to represent operating limitations for the different plant types, such as minimum and maximum output levels. Plant types that can operate with multiple fuels shall be represented in the model with multiple options for dispatch, where appropriate. The number of these options should be balanced with the additional complexity and model run-time and take into consideration regional variations in fuel availability and switching capability.

The dispatch model should represent operating reserves to the extent supported by the data for each region. Operating reserves should be allowed to increase as a function of intermittent/variable energy resource penetration, as a proxy to represent the increased needs for system flexibility, allowing for regional variation to reflect different regulatory and operational regimes.

The model should include the ability to assign some generators or portion of capacity as "must-run" to represent out-of-merit order dispatch or to address the over-optimization that may occur when limited cost data is available. However, these types of assignments lead to inflexibility in alternate scenarios, so the feature should allow for user-specified designations for specific plants or operating groups.

The model should be capable of representing dispatch in a chronological manner. The user shall be capable of varying the time steps of the chronological sequence. The model should represent time-coupled constraints (resource operating constraints that are linked across time intervals), if appropriate, and with adequate consideration to run-time implications.

The solution algorithm shall be capable of representing economic dispatch subject to the appropriate constraints in each model region. It shall be capable of producing marginal costs for energy in each region, as well as pricing on reserve constraints and pricing on transfer constraints between electricity regions, where applicable.

b. Capacity planning – expansion and retirements

Capacity planning decisions in the electric power sector include additions, retirements, and retrofits. Planning decisions need to incorporate a representation of investment and dispatching (merit-order) decisions in order to examine the tradeoff between capital and operating costs. The model should require sufficient capacity to meet a pre-specified reserve margin above the peak demand and compare the total costs over a multi-year period (e.g., 30-year cost recovery). The methodology should be responsive to changes in the primary drivers.

The planning decisions shall account for regional differences in reliability, representing different levels of loss of load expectation. The planning decisions shall account for the capacity values of different resource types, including attention to how such capacity values change with the penetration of renewables and mix of resource types.

Required inputs include technology cost and performance characteristics, electricity demands (distributed by load segment), fuel prices, and reserve margins, where applicable. Outputs include capacity additions, retirements, and retrofits so that available capacity by technology (fuel) type and region can be provided to the dispatching component. The model must also determine how capital investment costs impact the electricity price. The model should include a method to account for potential variance in levels of regulatory risk in new investment, both across regions and across technologies.

The model should increase the technology representation as discussed in the sections on Technology Representation and New Technology Choice. The solution algorithm depends on software compatibility with the rest of the WEPS+ system and runtime specifications, and shall be capable of representing least-cost capacity planning with economic decisions for expansion, retirement and retrofits. It shall be robust enough to represent policies as discussed in Section IV on Policy. It may be necessary to phase in the representation of the planning component as it is difficult to simultaneously implement additions, retirements, and retrofits. The current “exogenous” retirement inputs need to be replaced with an endogenous, economic-based methodology but the current framework could be utilized while the capacity additions algorithm is developed. The current model also does not include retrofits – a feature which is important for compliance with environmental regulations. In particular, carbon capture and storage (CCS) retrofits would be desirable to evaluate different carbon scenarios.

Strong consideration shall be given to combining capacity planning and dispatch into the same submodule of the model.

c. Renewables integration

In order to satisfy the requirements outlined in Section IV for a model that is responsive to environmental policies, including those related to greenhouse gas emissions, the model must be able to evaluate the use of low-carbon or zero-carbon resources such as renewables and nuclear. The model must accommodate the economic response of these resources as mediated by policy drivers and constraints. To the extent possible, the model should account for resource, technical, geographical attributes, and political factors that may constrain the growth of these resources.

Renewable resources included in the model should include, as data permits, wind, solar, hydro, geothermal, and biomass for power. Other resources may be included, and the model should be flexible enough to accommodate additional resources. Any given resource may be exploitable with more than one technology (such as thermal or photovoltaic capture of solar energy) or with multiple variants of a single technology (such as differing rotor specifications on a 3-blade upwind horizontal wind turbine). A single representative technology may be used in conjunction with each resource, but competing two or more technologies to exploit the same resource would also be acceptable (as long as the resource is not supporting more extractive capacity than physically possible). Technology-resource correspondence may also be determined exogenously for each region, if appropriate (for example, only allowing the model to build PV in some regions and solar thermal in others).

For hydro, wind, and solar resources, interactions with overall grid operations should be considered. Characteristics of these technologies, such as seasonal or diurnal energy limitations, intermittent production, and load/output correlation can significantly affect the economic fit of these resources, and should be accounted for in the model consistent with available data and model resolution. Some impacts may be deemed to occur at levels outside of the model scope and may be left out of the model or incorporated through exogenous factors.

d. Nuclear integration

Because of the significant realized and potential impact of exogenous factors in many countries pertaining to the ongoing use and future deployment of nuclear power sources, EIA expects to develop separate model structures for the routine evaluation of such capacity planning decisions. The electricity model must be able to accommodate exogenous specification of nuclear builds from both a dispatch and capacity planning perspective. However, in some cases – such as greenhouse gas policy cases – there may be a need to represent nuclear as an endogenous capacity expansion option, subject to exogenously determined determinants. The model shall allow the user to specify whether nuclear is endogenously planned by run-time specification.

e. React to technology advancements

  1. Technology representation – Fuel, Renewables, CCS

     The model is not intended to represent a comprehensive accounting of the various technologies available for electric power generation, but rather is intended to provide just enough detail to a) determine the impact of the electric power sector on global demand for fuels such as oil, natural gas, and coal and b) evaluate the impact of the electric power sector in responding to global environmental policy initiatives. It may be desirable to have separate treatment of generation technology and generation fuel, to the extent that some technologies are capable of supporting multiple fuel types (either chosen at the design stage or for normal operating flexibility).

     Fuels represented in the model should represent those commonly traded and utilized by the electric power sector worldwide, and must include coal, natural gas, petroleum (and/or other substitutable liquid fuels), biomass, and nuclear fuels. Other fuels may be included in the model specification, but EIA will consider the relative analytic benefits against the cost of maintaining model structure for other fuel types. The model should be flexible enough to accommodate changes in the fuel suite represented, including adding new fuel types and removing fuel types that may at some point be deemed no longer worthwhile to represent. Adding and removing fuels from the fuel suite should be a simple process requiring no coding changes or recompilation.

     Conversion technologies should include a sufficient range of commercially available technologies to represent the utilization of all the fuels modeled and to ensure reasonable economic coverage over the load duration curve. At a minimum, the model must have at least one technology capable of using each fuel represented. The model must also have technologies that are generally seen as economic to meet each of the key duty cycles implied by the load duration curve, including peaking plants, baseload plants, and plants that can operate in a load-following mode. EIA will consider factors such as the widespread use of a particular technology, the competitive landscape for new builds in the current market, and the potential for continued or future deployment when evaluating recommended choices of conversion technologies.

  2. New technology choice

In addition to modeling commercially available technologies with widespread application, in order to adequately represent greenhouse gas policy the model must have an ability to choose from a reasonable suite of low, zero, or negative carbon-emitting technology/resource combinations. Technologies that do not meet the criteria for widespread deployment or current economic viability should also be included if they have high potential to respond to future policy for greenhouse gas reductions. In particular, technologies that are capable of capturing and sequestering carbon dioxide produced by fossil- or biomass-fueled plants should be included. The modeler should consider "downstream" treatment of captured emissions when evaluating the inclusion of carbon-capture technologies. Many renewable and nuclear technologies will also fit into this category of "non-commercial with high potential," and may be recommended for inclusion.

EIA will consider the availability and quality of data pertaining to cost, performance, and resource characteristics when evaluating new technologies to represent in the model. Consideration will also be given to the impact of adding new technologies on model performance, and the potential impact on results, in both market and policy-driven cases.

Capacity expansion decisions, discussed in Section II b., will be made using both current and new technologies. In some cases, there may be a need to include "legacy" technology representations for technologies with significant levels of deployment currently but with little assessed potential for future deployment (such as through obsolescence). In such cases, the model should be capable of representing these technologies for dispatch without representing them for capacity expansion. In other cases, some pre-commercial technologies may be assessed as being useful to include in the model, but too far removed from commercial deployment for near-term capacity planning. In such cases, the model should be able to specify criteria such as an initial start year or economic/policy milestone that would allow the technology to enter into the capacity planning decision-making.

3. Technology learning

Given the initial suite of technologies represented (see Section II e. 1.), the model should appropriately account for the dynamic characteristics of these technologies. In particular, the model should incorporate structures to evaluate learning-by-doing impacts on technology cost and performance assumptions. Structure may also be incorporated to evaluate the impact of technology improvement (cost and/or performance) resulting from time-dependent factors, the tendency to underestimate costs for pre-commercial technologies, as well as from exogenous factors. The complexity of the technology improvement structures used will be evaluated against the benefit provided in being able to accurately represent cost reductions within a technology class and across classes of related technologies and the responsiveness to different policy and market factors that may impact technology cost and performance (for example, are learning-by-doing effects accounted for separately as a result of government funded R&D programs or from macro-economic effects). However, to the extent that additional detail detracts from the usability of the model, requires data that is not readily available, or requires extensive operator maintenance, simpler model structures may be preferred.

Consideration should also be given to representing learning that may occur on globally available components (turbines, PV modules, and so forth) and system elements that are inherently local in nature (such as installation costs and balance-of-system costs). Technology cost and progress toward learning may differ among regions within the model, but should have some correlated behavior resulting from the strong potential for international trade in physical components and knowledge that is characteristic of many of the technologies that may be included in the model.

Consideration should also be given to representing the effect of learning when two different technologies share certain common components that constitute a significant portion of system cost. For example, combustion turbines may be used alone or in conjunction with a heat-recovery steam generator, and may be fed directly by natural gas or fuel oil, or potentially by gasification of a solid fuel. Therefore, one might expect technology improvements in combustion turbines to be reflected, at least to some degree, in three potential technology representations (simple turbine installations, gas-fired combined cycle units, and integrated gasification of coal for combined cycle installations).

III. Produce an end-use price (including subsidies and taxes)

EIA desires a model that can project prices for electricity in various regions around the world, both wholesale and retail. The model shall produce prices that are responsive to changes in capacity mix and fuel costs, and shall represent region-specific taxes and subsidies (historic and expected).

There are many methods of regulation around the world, and the ideal international electricity model would be capable of representing different methods of regulation by country (e.g., cost-of-service, revenue-cap, etc.). A future phase of model development could endeavor to represent a slate of different regulatory methods, allowing the user to select the method that applies to each country in order to represent different regulations by region or by country.

In this phase, the model should take a simplified approach. The model shall be able to calculate average cost prices and marginal cost prices for each electricity region, similar to the approach used in the NEMS EMM, in which cost-of-service and competitive pricing is calculated for each EMM region. The user shall be capable of specifying whether an electricity region uses average cost pricing, marginal cost pricing, or a blending of the two methods, and the model should apply the chosen approaches as specified.

Average cost prices shall be based on average production costs, including capital and other costs. In order to address the issue of capital recovery, while avoiding the unwieldy task of completely accounting for existing asset bases in every country, the model shall take a simplified, generic approach to the accounting of existing assets. The simplified approach could include methods such as utilizing the levelized costs of new plants for all generation, or developing estimates of historical values.

The model shall calculate marginal cost wholesale prices by electricity region and time step. The model shall also be capable of representing capacity prices for competitive regions, based on a method that represents the incremental cost of maintaining resource adequacy (such as the shadow prices on planning reserve margin constraints). Marginal cost pricing will be used in projections for electricity regions where appropriate.

Sector-level retail prices (residential, commercial, industrial) shall be developed using region and sector-specific adjustments that can reflect historical and expected taxes and subsidies. The model shall also contain country-specific adjustment parameters to reflect historical costs for intra-regional transmission and distribution. The model shall project generation, transmission, and distribution components of retail prices over the forecast horizon.

IV. Overarching Requirements

These requirements specify how the IEMM shall interact with the World Energy Projection System Plus (WEPS+). Both IEMM and WEPS+ support the publication of the International Energy Outlook (IEO).

a. Software Requirements and Availability

1. The model shall be written in a language/platform that can be called from the WEPS+ integrating module, which is written in Python. Where optimization is used, the mathematical programming formulations (sets, parameters, variables and equations for LPs, MIPs, etc.) shall be coded in AIMMS (or equivalent; justification must be provided to deviate from AIMMS as a mathematical programming platform). If the model will be run on a separate platform from WEPS+, a communication protocol shall be developed that allows for automated communication between WEPS+ and the model. For example, WEPS+ is typically run on a Windows 7 PC or on a single core of a Windows 2008 Server. If IEMM runs on a parallelized Linux cluster, then IEMM must be able to communicate with WEPS+ without requiring that WEPS+ be installed on the same cluster.

2. EIA will consider overall run time and contribution of each component to run time when evaluating each model.

3. The model source code shall be developed as public domain software material. The model shall be developed with the intent that the source code may be modified by EIA staff for model maintenance, updates, or enhancements. Licensing agreements shall not preclude EIA staff from making changes to the source code or model input. EIA staff shall be capable of sharing the source code with other entities for any purpose without charge.

b. Data Requirements and Sources

1. The model shall receive input data from WEPS+. These inputs include, but are not limited to:

    a. Electricity demand - by region, sector, and year
    b. Fuel prices - by region and year

2. The model shall send output data to WEPS+. These outputs include, but are not limited to:

    a. Electric generating capacity - by region, fuel, and year
    b. Electricity generation - by region, fuel, and year
    c. Fuel consumption in the power sector - by region, fuel, and year
    d. End-use (retail) electricity prices - by region, sector, and year

2. The model shall communicate with WEPS+ through the WEPS+ binary restart file.

    a. The restart file specifications are already defined.
    b. The model shall use the predefined communication specifications.

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4. Where proprietary, third-party data sets are used, the contractor shall be responsible for obtaining all necessary license permissions to use the data. Any intended use of third-party data as model input shall be agreed to by EIA staff before contract activities commence. In cases where EIA staff rejects the use of third-party data, appropriate substitutes of publicly available data sources shall be used.

c. User Inputs

   1. The user shall be able to modify model assumptions without accessing or recompiling source code.

   2. The model should use an input file format agreed upon by the users and the model developers. This format may be Excel, an SQL database, or another format appropriate for both model operation and user modification.

d. Geographic Representation

   1. The model shall represent electricity regions at a sufficient level of granularity to capture the distinct features of major electricity markets around the world. This may include regions that are combinations of countries, individual countries, or sub-regions of individual countries. A constraint on choice of regions is that individual regions shall be subsets of the 16 IEO regions (up to and including representing a whole IEO region as an electricity region). Attention shall be given to representing existing power pools and inter-country electricity markets as distinct regions, to the extent feasible. Major countries that are not substantially electrically connected to other countries should be represented as distinct electricity regions. Transfer limits between electricity regions shall be defined based on the best information available. Where information is available, imports and exports of electricity between nations shall be accounted for in the model.

      The model shall output projections for the 16 IEO regions:
      a. United States
      b. Canada
      c. Mexico/Chile
      d. OECD Europe
      e. Japan
      f. Australia/New Zealand
      g. South Korea
      h. Russia
      i. Other Non-OECD Europe and Eurasia
      j. China
      k. India
      l. Other Non-OECD Asia
      m. Middle East
      n. Africa
      o. Brazil
      p. Other Central and South America

However, the model could solve at a more granular level and then aggregate output data, to the extent that data allows.

3. The model shall have the capability to output projections for different regions with minimal reprogramming, and ideally as specified by a user prior to running the model. Changes include the addition or subtraction of regions as well as the addition or subtraction of countries within regions.

4. The model may run at whatever geographic level best represents global electricity markets, as long as the output can be sent to WEPS+ at a level of detail for the 16 IEO regions.

e. Time Horizon and Granularity

1. The model shall provide annual projections to WEPS+ over the same time horizon as the IEO. The current time horizon ends in 2040, but is periodically adjusted forward in time to maintain an approximate 25 to 30 year forecast horizon.

2. The model shall be able to extend the annual time horizon to match any changes in the IEO time horizon.

The model may run at any temporal granularity, as long as the results can be output as annual projections. For test purposes, model results should also be available at "native" granularity.

f. Scenario analysis capability – React to policies (specifically carbon case scenarios)

EIA will be using this model to evaluate market responses to global energy policy initiatives. In particular, EIA may need this model to assess the impacts of international greenhouse gas controls or taxes. To that end, the model must be able to endogenously represent a reasonable range of low-carbon, zero-carbon/carbon-neutral, or negative-carbon technologies that can react directly within the model to policy factors or that can indirectly react to economic factors resulting from policy decisions. The model should be capable of representing a range of policy design, including "cap-and-trade," feed-in-tariffs, direct subsidy/tax subsidy, and carbon fees or other Pigouvian taxes visible to the electric power sector. Flexibility to represent other policies that may be coordinated on an international basis to address environmental or other economic, social, or political factors would be desirable, but this flexibility would need to be weighed against the upfront and going-forward costs of building and maintaining such structures.

Capability to endogenously represent policies other than greenhouse-gas related policy may or may not be incorporated into the initial structure of the model, but the ability to represent them in future versions of the model should be among the factors considered when selecting a model structure and platform. Modeling approaches, languages, and platforms that offer greater customization potential would generally be seen as having greater potential to accommodate future scenario requests. However, EIA will weigh the benefits of this future flexibility against its impact on the usability of the current model. That is, if the flexibility increases model complexity too much, or necessitates using a modeling language with limited support and a high learning curve, then preference may be given to less flexible models that meet the minimum greenhouse gas requirements, even if they exhibit higher ease-of-use factors.

g. Foresight and Expectations

Capacity planning decisions are evaluated over a multiyear period so they require estimates of future trends in key parameters such as electricity demands and fuel supplies. Foresight methodologies generally fall into three categories – myopic, adaptive, and perfect. Myopic expectations use current or historical values for the entire cost recovery period. Adaptive expectations apply recent trends (e.g., growth rates) to future prices and quantities. Perfect foresight assumes the results for future drivers are known, or are at least consistent with the values that ultimately occur.

The model shall include foresight, and the methodology shall be explained in detail in component design reviews.

V. OPERATING CONSTRAINTS

a. The CDR authors and implementers of the model (both prototype and full model) may or may not be the same party.

b. The actual model design that gets implemented may not necessarily be one that is proposed in a CDR. The actual model design may incorporate several CDRs from different sources. Therefore, the government shall retain unrestricted rights to all CDRs developed.